Total Organic Carbon Variability in the Utica Shale of Northwest Ohio

Senior Thesis
Submitted in partial fulfillment of the requirements for the
Bachelor of Science Degree
At The Ohio State University

By

Kyle J. Cox
The Ohio State University
2012

Approved by

David R. Cole, Advisor
School of Earth Sciences

Abstract

The Utica Shale is an Ordovician age rock unit found throughout most of Ohio and much of the Northeastern United States. Recently, the Utica's potential as a source and reservoir for hydrocarbons (oil and natural gas) has become an important topic in Ohio. If the Utica contains large amounts producible of oil and gas, the economic impact on the state could be very significant. Due to its hydrocarbon generating potential, there is a great amount of ongoing research focusing on the Utica. Most of this investigation targets the Utica in Eastern Ohio since geologic factors in the area (history of oil and gas production, the unit resides within a window of ideal formation depth below the surface) and preliminary explorations indicate a high likelihood that producible amounts of hydrocarbon reside in the formation in that part of the state. Similar factors (though not as ideal) may exist in the Northwestern portion of the state, however little research has considered this area. The purpose of this study was to investigate the hydrocarbon potential of the Utica Shale in Northwestern Ohio by measuring TOC values of rock samples from the area, and investigating how these values vary throughout the area. Total Organic Carbon, more commonly referred to as TOC, is one important indicator of a geologic units potential as a source rock. It is a measurement of the concentration of organic material in a rock which is necessary for the generation of hydrocarbons. TOC measurements from the Utica in Northwest Ohio were obtained by acidifying rock samples from the Utica in the study area to remove

Inorganic Carbon from the samples followed by combusting them in an Elemental Analyzer which measured the remaining, and thus organic, Carbon. 34 samples were obtained from 16 wells in 10 counties of Northwest Ohio. Results showed limited hydrocarbon potential for the area. The average TOC was 1.38% and the 34 samples ranged from 0.73 to 2.75% TOC with the majority of samples falling between 1 and 2%. No strong trends in the variability of the TOC by location were identified. Future research following the same methodology with a larger sample area or a closer-spaced sample frequency across the study area could reveal trends that were too broad or narrow to be identified by measuring the sampled wells.

List of Tables, Charts, and Maps

Table of Contents

Introduction

Shale Reservoirs:

As energy demands increase, oil and gas companies are looking to exploit unconventional reservoirs to produce hydrocarbons. Shales rich in organic content are one of these unconventional reservoirs. Shale reservoirs are considered unconventional because their low permeability makes it very difficult produce hydrocarbons from them, but new techniques such as hydraulic fracturing and horizontal drilling have made it possible to extract economic amounts of oil and gas from them. Many different reservoir parameters need to be assessed to judge whether a shale reservoir can be commercially produced. Some of these parameters are porosity (space in the formation for the hydrocarbons to reside), permeability (can the oil and gas move between pores), clay/carbonate content (both affect hydraulic fracturing), formation pressure (pressure to push oil and gas up the well), thermal maturity (has the formation been at temperatures necessary to produce hydrocarbons from organic content), and total organic carbon. Total organic carbon (TOC) levels of a possible shale reservoir are the focus of this study. TOC is the weight percent of organic carbon in a rock. In shale this carbon comes from organic material such as the remains of algae, plankton, plants, and etc. that are deposited along with the sediment that will become the shale. Organic carbon in rock becomes oil and gas when brought to a high enough temperature. The temperature is raised when the rock is buried beneath the surface during diagenesis. Rock that has not reached a high enough temperature is "immature" and the organic carbon has not been "cooked" into hydrocarbon, and rock that has been at too high of a temperature for too long are "over mature" with some or sometimes all of the carbon converted into carbon dioxide. Rock units of thermal maturity levels in between these two end members and containing sufficient TOC can produce oil and gas. 2% TOC is considered the minimum in the oil and gas industry for a shale gas reservoir to be commercially viable, but greater than 3% is desired (Gutierrez et al, 2009)

The Utica Shale:

The Utica Shale is an Upper Ordovician unit that underlies much of the Northeast US and parts of Canada including New York, Pennsylvania, West Virginia, Ohio, Michigan, and Ontario. The Utica was deposited during the late Ordovician in a basin in the epeiric sea that covered much of what is now the United States (Hansen, 1997). This basin was surrounded by carbonate platforms which contributed high levels of carbonate to the Utica (Ryder 2008). It is speculated to have great potential as an oil and gas producer, especially in eastern Ohio where its level of thermal maturity indicates a high likelihood that large amounts of "wet" gas and oil are contained within the formation as opposed to less profitable "dry" gas (Yost, 2011). The formation becomes less mature to the west as it shallows as and leaves the Appalachian Basin. In the study area, the Utica deepens to the North West as it enters the Michigan Basin. The Utica most likely becomes more mature in this direction, which provided the motivation for this study. Northwestern Ohio was also chosen based on historic oil and gas production in the area and a lack of understanding of the Utica formation in the area.

Objectives

The goal of this research was: to investigate Total Organic Carbon levels of the Utica Shale formation in Northwestern Ohio, identify if the levels varied by location, and find any trends in how the levels varied within the study area. These goals were to be completed through testing four hypotheses: TOC will vary horizontally across the formation, TOC will vary vertically within the formation, TOC will vary with depth of the formation below the surface, and there will be a layer of relatively high TOC at the base of the formation. The hypothesis for horizontal variability was tested by taking measurements on samples from 16 wells spread across the study area that were compared based on their geographic position. The hypothesis for vertical variability was tested by sampling from 2 or 3 depths within the formation for each sampled well and comparing the deepest sample from a sampled well with shallower samples of the same well. The hypothesis for variability according to depth below the surface was tested by taking measurements from 34 samples from depths ranging from 880 to 2471 ft. The hypothesis for the existence of a high TOC layer at the base of the formation was tested by making measurements on 16 samples that came from less than 20 feet above the Utica-Trenton contact and comparing them to measurements of samples not near the contact.

Methods

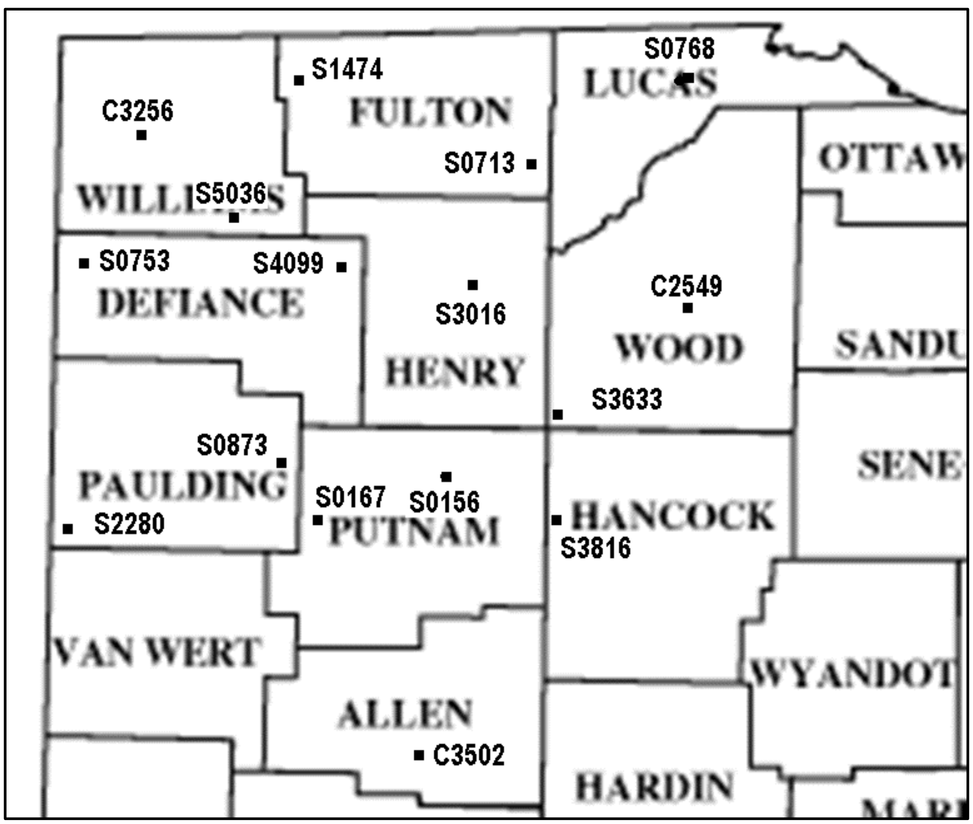
Sampling:

34 samples of the Utica Shale from 16 wells in 10 counties from the study area were acquired (Table 1). Samples were provided by the Horace R. Collins Core and Sample Repository of the Ohio Department of Natural Resources in the form of 2 to 3 grams of cuttings or ¼ core from oil and gas wells. The sampled wells were chosen based on three criteria: testing the hypotheses, written core/cutting descriptions, and availability. To test the hypotheses of horizontal variability, samples from sixteen wells spread across the study area were chosen. To test the hypothesis of vertical variability two or three samples were taken from depths ideally 50 to 100 ft. apart. To test the hypothesis of variability with depth samples were taken from large range of depths (880-2467'). To test the hypothesis of the existence of a basal organic rich layer samples were taken from as near the Utica-Trenton Contact as possible. Core/Cutting descriptions provided by the Ohio Geological Survey were consulted before sampling to identify the depth of the Utica within the well. Availability of samples from the Utica in Northwestern Ohio was very limited with many of the wells missing large intervals of the formation, causing undesired irregularity in the sampling frequency (Map 1).

Table 1: Sample information

Well	API Number	County	Township	Latitude	Longitude	Depths Sampled
C3502	34003636910000	Allen	Shawnee	40.71206389	-84.13046581	1220, 1245
S0753	34039200040000	Defiance	Milford	41.38353696	-84.74707902	1794-1821, 1849-1857
S4099	34039200650000	Defiance	Adams	41.39141821	-84.29830309	1770-1800, 1850-1860
S1474	34051200240000	Fulton	Gorham	41.66711337	-84.34525839	2389-2398, 2467-2471
S0713	34051200120000	Fulton	Swan Creek	41.54577523	-83.9251376	1785-1794, 1911-1917
S3816	34063202800000	Hancock	Blanchard	41.04483727	-83.87949517	1290-1300, 1330-1340
S3016	34069200360000	Henry	Harrison	41.3581122	-84.02747589	1583-1653, 1677-1713
S0768	34095200280000	Lucas	Toledo	41.61614867	-83.67900686	1250-1260, 1340-1350
S2280	34125200060000	Paulding	Benton	41.04324275	-84.77582227	1284-1292, 1347-1355
S0873	34125200040000	Paulding	Brown	41.09819974	-84.42975737	1190-1195, 1380-1385
S0156	34137200310000	Putnam	Liberty	41.09539148	-84.08948167	1359-1362, 1400-1410
S0167	34137900290000	Putnam	Perry	41.030403	-84.322815	1174-1180, 1394-1351
S5036	34171200650000	Williams	Pulaksi	41.44262	-84.56656	1840-1850, 1920-1930
C3256	34176000400000	Williams	Superior	41.55895233	-84.65613149	2090, 2190, 2265
S3633	34173203820000	Wood	Jackson	41.18074812	-83.85421251	1390, 1458
C2549	34173611040000	Wood	Portage	41.32158411	-83.64954875	880, 980, 1080

Map 1: Geographic location of the sampled wells



Sample Preparation:

Samples were ground to a fine uniform powder before they could be analyzed. Carbon from inorganic sources such as calcite and dolomite were removed because the Costech elemental analyzer used to measure the TOC does not differentiate between carbon from inorganic and organic sources. 1.5-2 grams of sample were ground with mortar and pestle. 5-15 mg of this powdered sample was then placed in silver capsules. Inorganic carbon was eliminated through acidification methods adapted from Schumacher (2002). Hydrochloric acid was reacted with the inorganic carbon to convert it to carbon dioxide. Two rounds of acidification of samples using a total of 5 acid baths were necessary to remove all of the inorganic carbon. 10 µl of DI water was added to the samples prior to any acid to prevent any sample loss due to a possible energetic reaction that could eject sample material. 20 µl of a 10% HCl acid solution was applied for each acid bath. There was at least a 15 minute period between acid baths to allow the samples to fully react. 3 acid baths were applied during the first round of acidification. The samples were put in an 80° C oven overnight to dry out after each round. 2 more acid baths were applied during the second round. None of the samples showed any signs of reaction during the second round. Finally, the silver capsules containing the samples were folded into balls to prevent sample loss during testing in the elemental analyzer.

Elemental Analysis:

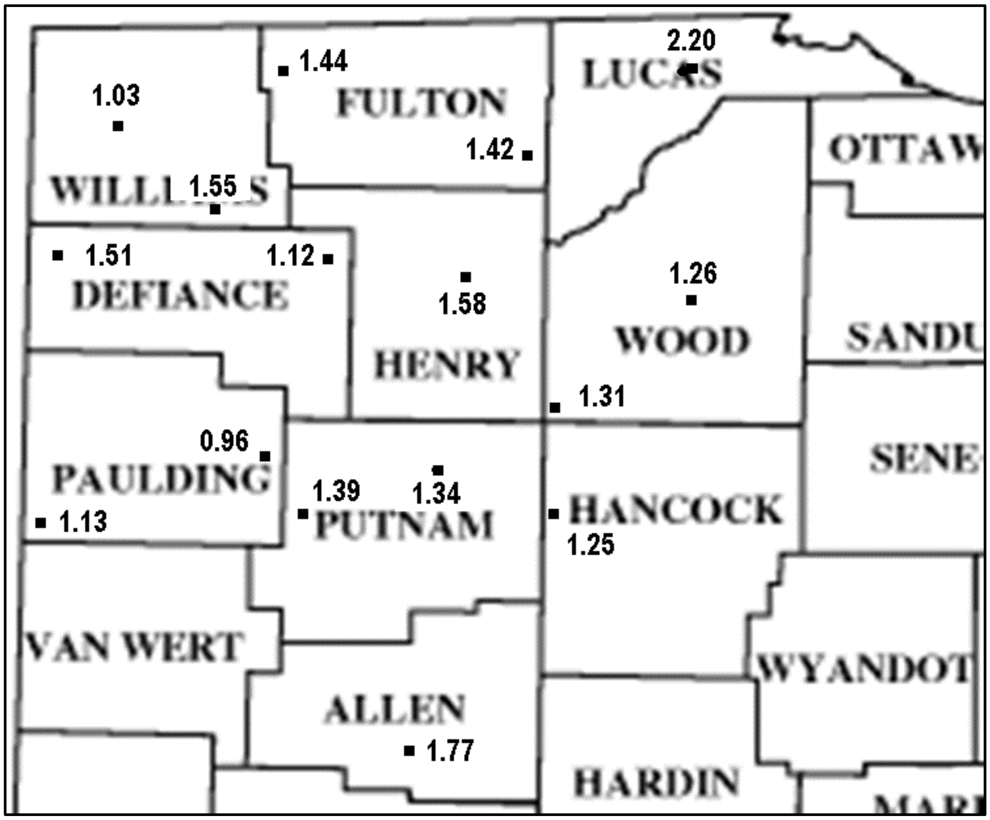
Total Organic Carbon measurements were made using a Costech ECS 4010 CHNSO Analyzer to perform elemental analysis on the samples. This analyzer used combustion analysis by flash combustion of prepared samples at temperatures from 1700-1800° C. This causes the samples to break down into nitrogen gas, carbon dioxide, water vapor, and sulfur dioxide. The amount of each gas released by the sample during combustion is measured by the analyzer using gas chromatography. The analyzer takes the amount of each gas released to calculate the weight percent of carbon, hydrogen, nitrogen, and sulfur in the original sample. The analyzer was calibrated with an acetanilide standard at the beginning of each round of testing and after every 10-12 samples run during each round. 3-5 measurements were made on each sample.

Results and Discussion

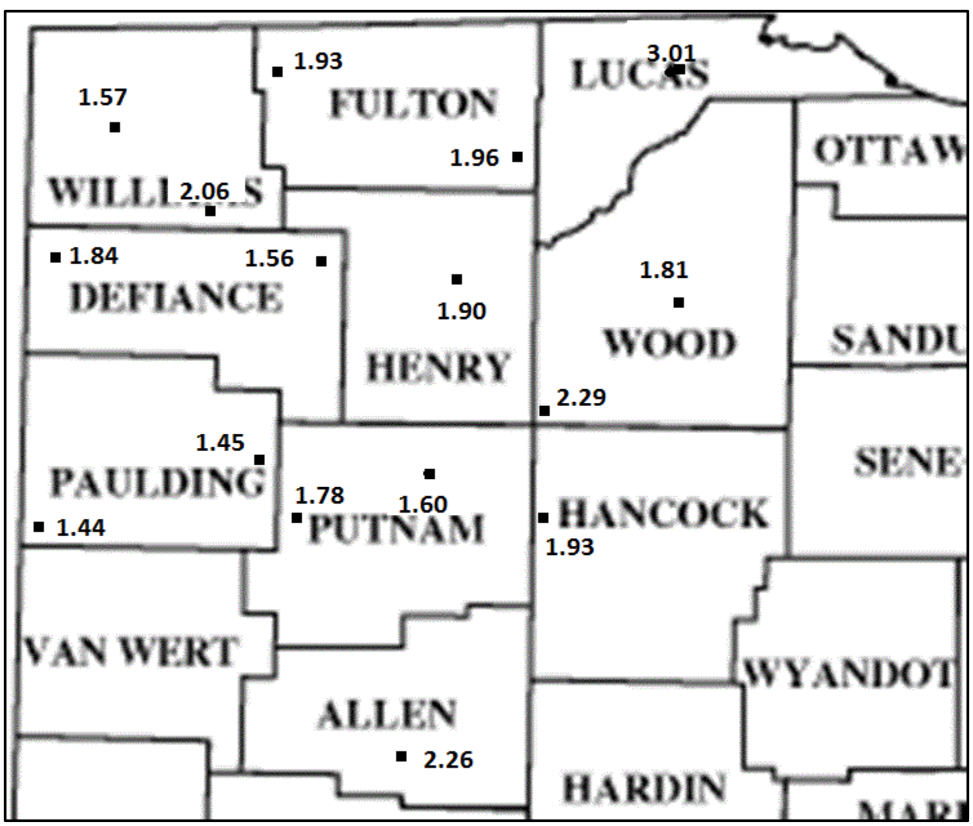
Table 2: Showing each individual TOC measurement and average for each sample, average for each well, difference between the bottom and top average (Average TOC bottom sample minus Average TOC top sample), the interval between the samples, and Change per foot (difference/interval).

Well	Depth (ft.)	TOC 1	2	3	4	5	Average	Well Average	Difference	Interval	Change per foot
S1474	2389-2398	1.58	1.58	1.14	1.93		1.56	1.44	-0.24	75.5	-0.0031
	2467-2471	1.29	1.26	1.32	1.41		1.32				
S0156	1359-1362	1.28	1.37	1.49	1.60		1.44	1.34	-0.20	44.5	-0.0046
	1400-1410	1.31	1.26	0.97	1.40		1.23				
S2280	1284-1292	1.09	1.04	0.99	1.26		1.09	1.13	0.07	63.0	0.0011
	1347-1355	1.27	0.86	1.09	1.44		1.16				
S5036	1840-1850	1.62	1.46	1.52	1.44		1.51	1.55	0.08	80.0	0.0010
	1920-1930	2.06	1.35	1.47	1.49		1.59				
S0768	1250-1260	2.60	2.83	3.01	2.53		2.75	2.20	-1.09	100.0	-0.0109
	1340-1350	1.73	1.64	1.59	1.68		1.66				
S3816	1290-1300	0.82	0.77	0.88	0.98		0.86	1.25	0.77	40.0	0.0191
	1330-1340	1.53	1.93	1.65	1.40		1.63				
S3016	1583-1653	1.52	1.54	1.81	1.39		1.56	1.58	0.03	77.0	0.0004
	1677-1713	1.37	1.47	1.90	1.65		1.60				
S0753	1794-1821	1.33	1.67	1.54	1.41		1.49	1.51	0.05	45.5	0.0011
	1849-1857	1.84	1.62	1.33	1.37		1.54				
S3633	1390	1.29	1.23	1.30			1.27	1.31	0.07	68.0	0.0011
	1458	1.21	1.34	0.55	2.29		1.35				
S4099	1770-1800	0.44	0.46	1.47	0.56		0.73	1.12	0.77	70.0	0.0109
	1850-1860	1.56	1.47	1.43	1.54		1.50				
C3502	1220	1.89	1.56	2.26	1.86		1.89	1.77	-0.25	25.0	-0.0099
	1245	1.90	1.65	1.60	1.07	2.01	1.65				
S0713	1785-1794	1.67	1.49	1.96			1.70	1.42	-0.57	124.5	-0.0046
	1911-1917	0.93	0.93	1.54			1.13				
S0873	1190-1195	0.43	1.01	0.96			0.80	0.96	0.32	190.0	0.0017
	1380-1385	1.20	1.45	1.02	0.70	1.25	1.12				
S0167	1174-1180	1.40	1.36	1.39	1.31	1.45	1.38	1.39	0.01	195.5	0.0001
	1394-1351	1.55	1.08	1.63	1.27	1.44	1.39				
C3256	2090	0.55	0.97	0.43	0.46	0.71	0.62	1.03	0.51	175.0	0.0029
	2190	1.40	1.57	1.16	1.16	1.33	1.32				
	2265	1.53	1.17	0.82	1.20	0.98	1.14				
C2549	880	0.82	0.96	1.01	1.01		0.95	1.26	0.66	200.0	0.0033
	980	1.40	1.04	1.10	1.19	1.40	1.23				
	1080	1.65	1.69	1.81	1.47	1.46	1.61				
Average							1.38	1.39	0.06	98.3	0.0006

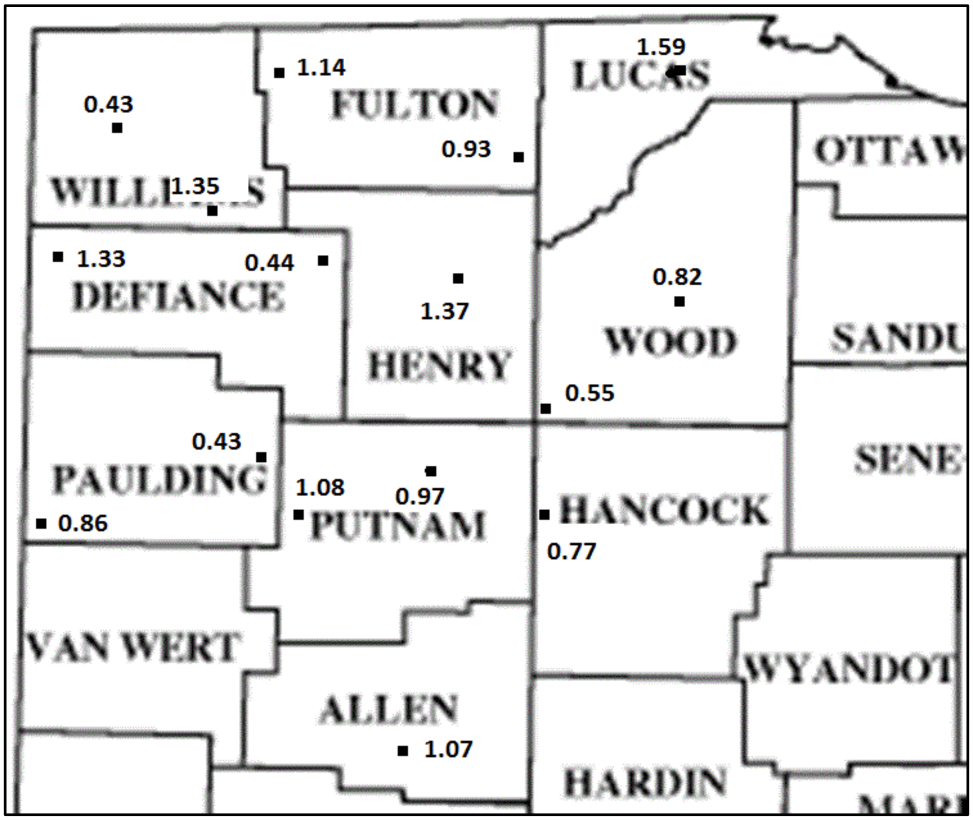
Map 2: Well Average TOC



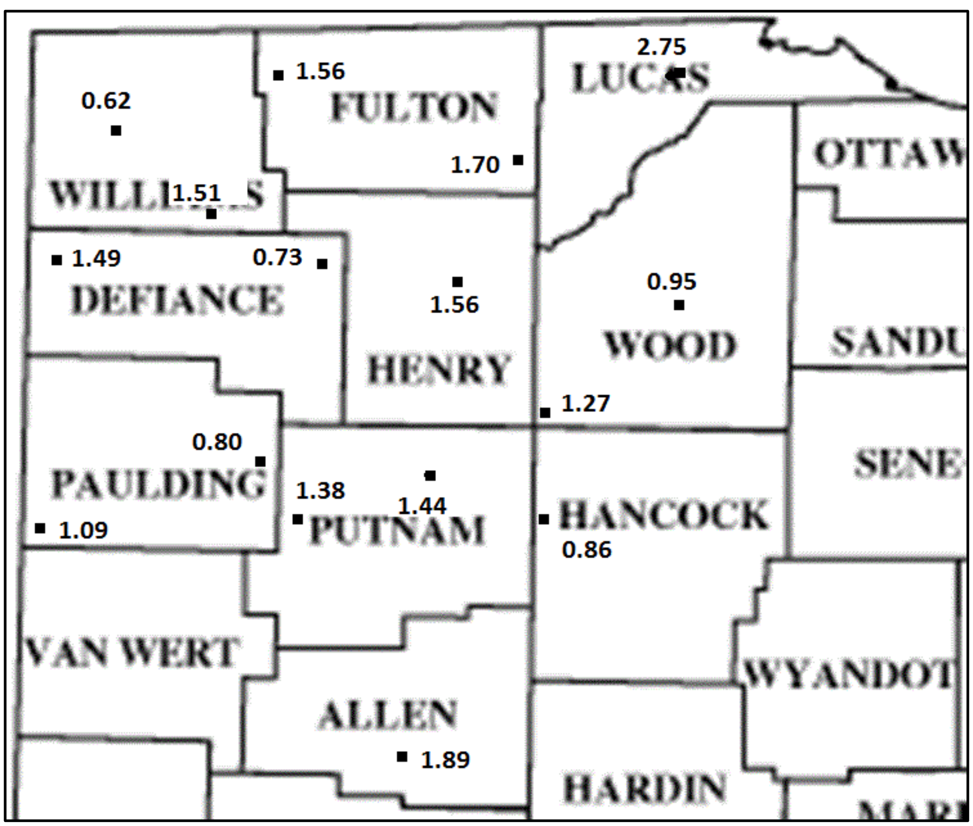
Map 3: Highest TOC Reading



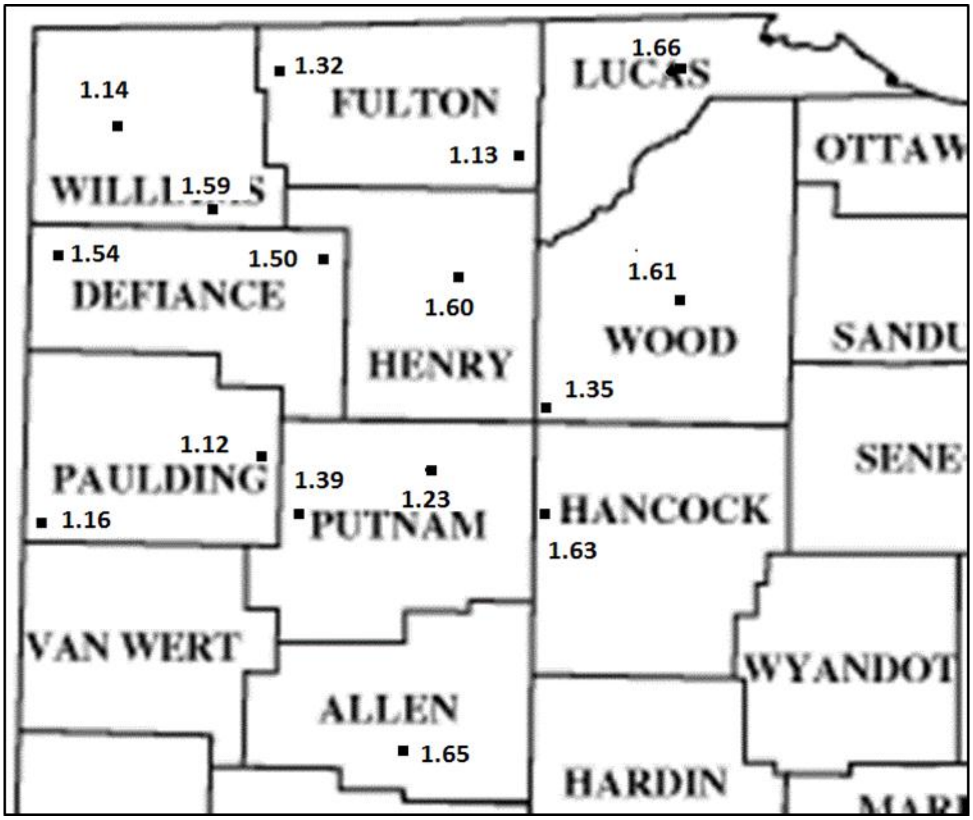
Map 4: Lowest TOC Reading



Map 5: Top Sample Average



Map 6: Bottom Sample Average



Map 7: Change with Increasing Depth (Ave. Bottom TOC – Ave. Top TOC)

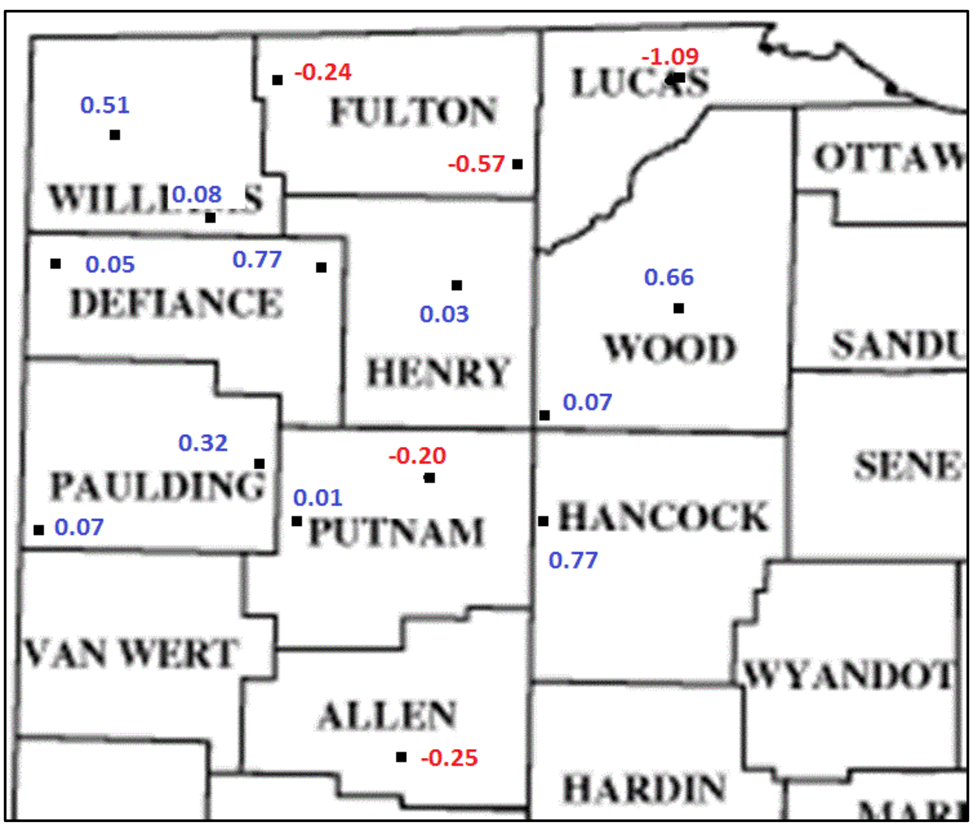


Chart 1

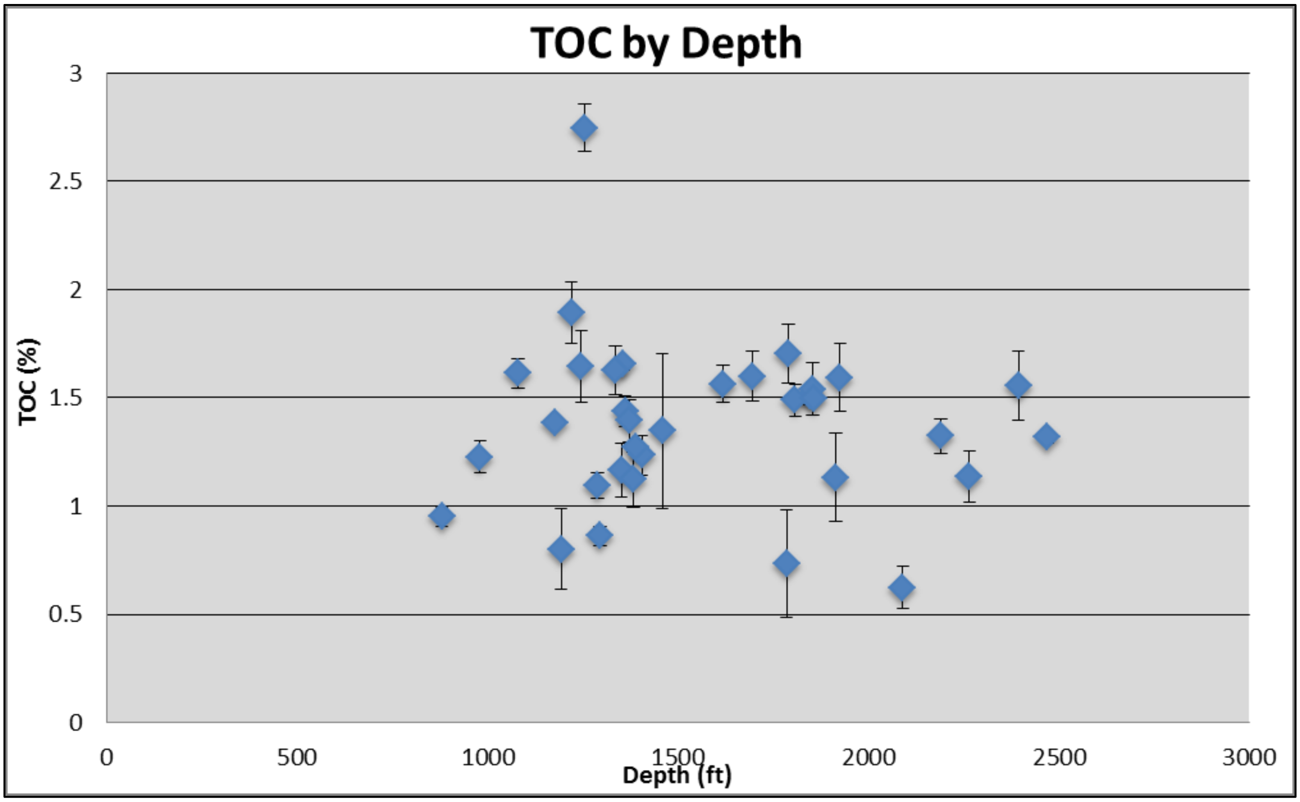


Chart 2

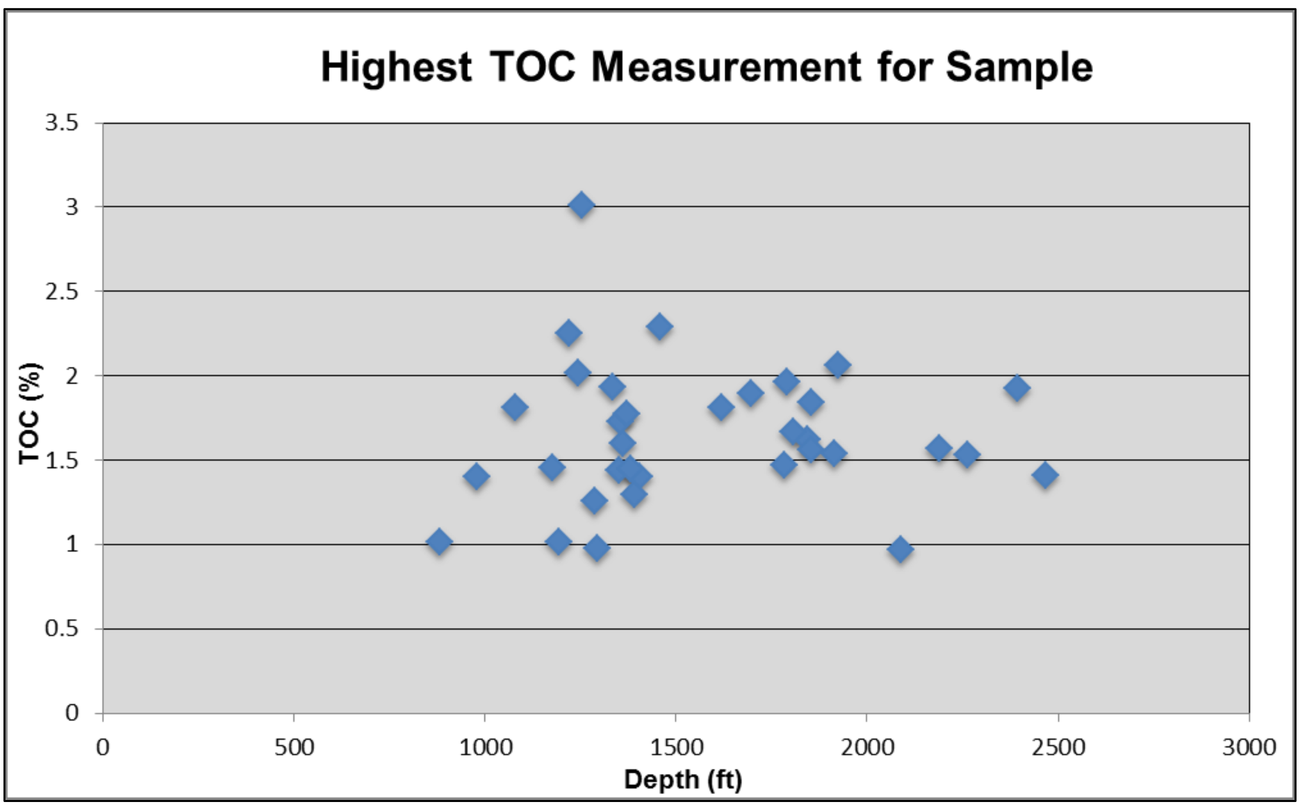


Chart 3

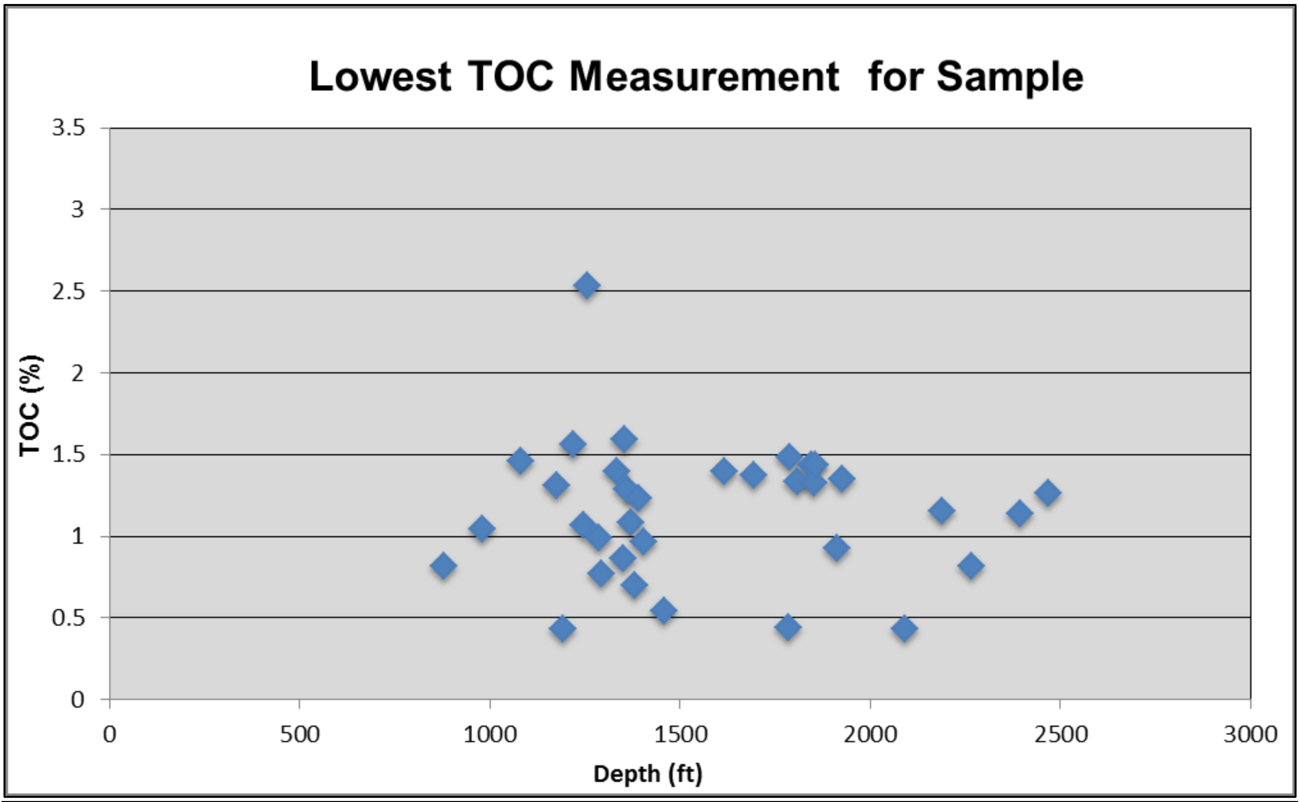


Chart 4

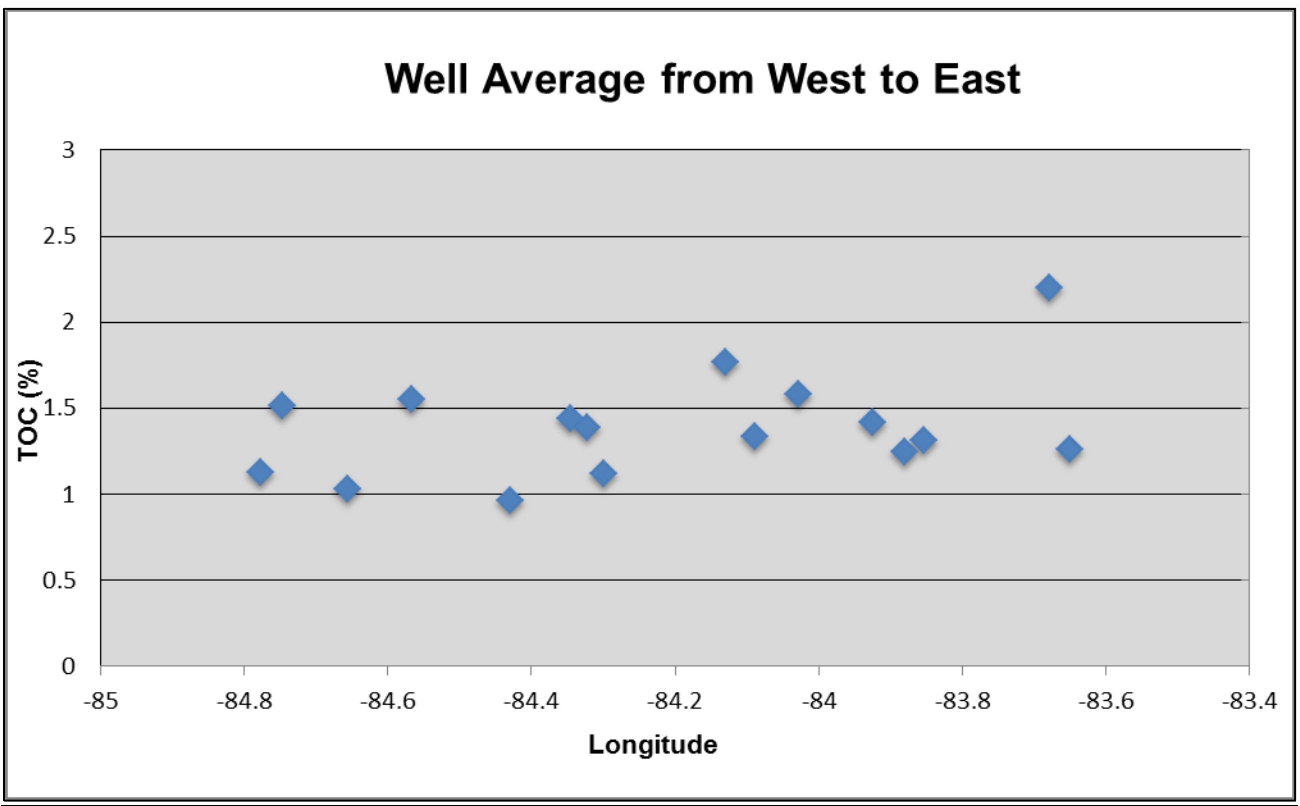


Chart 5

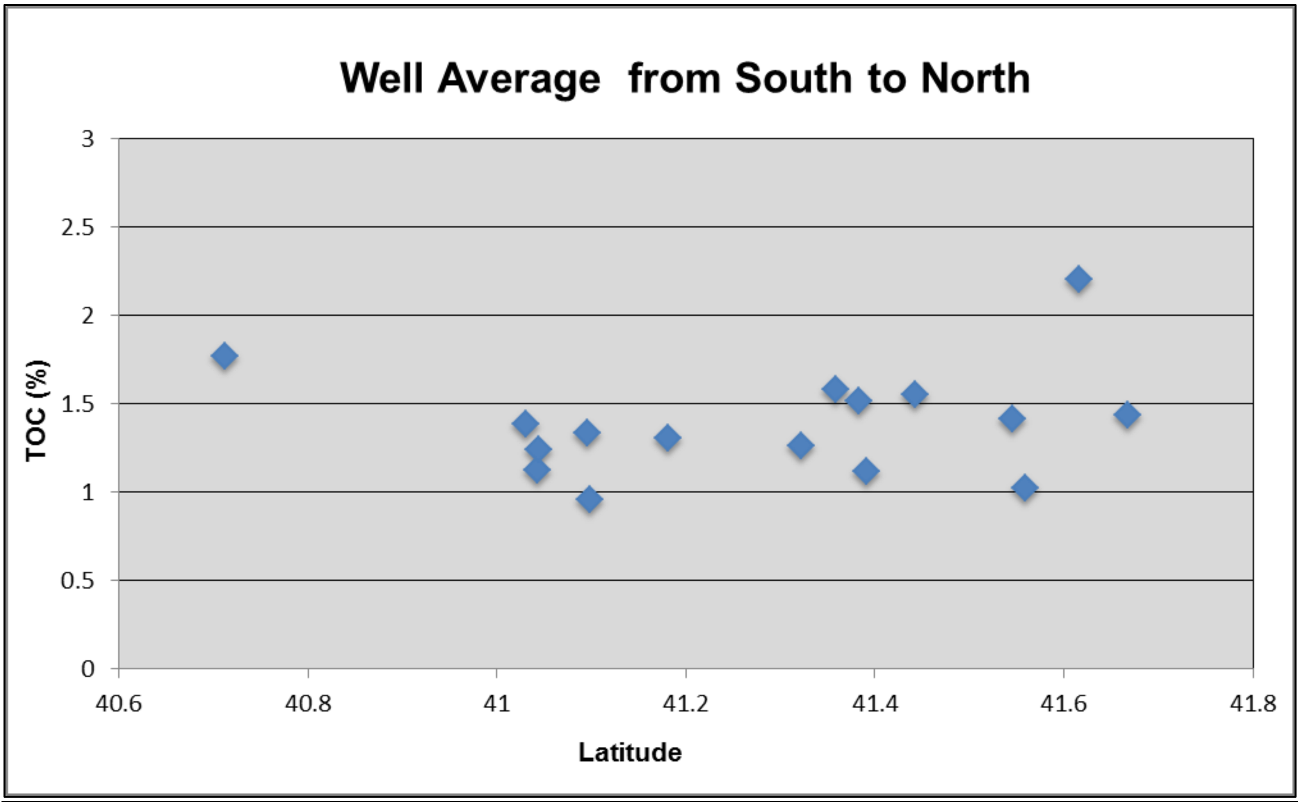


Chart 6

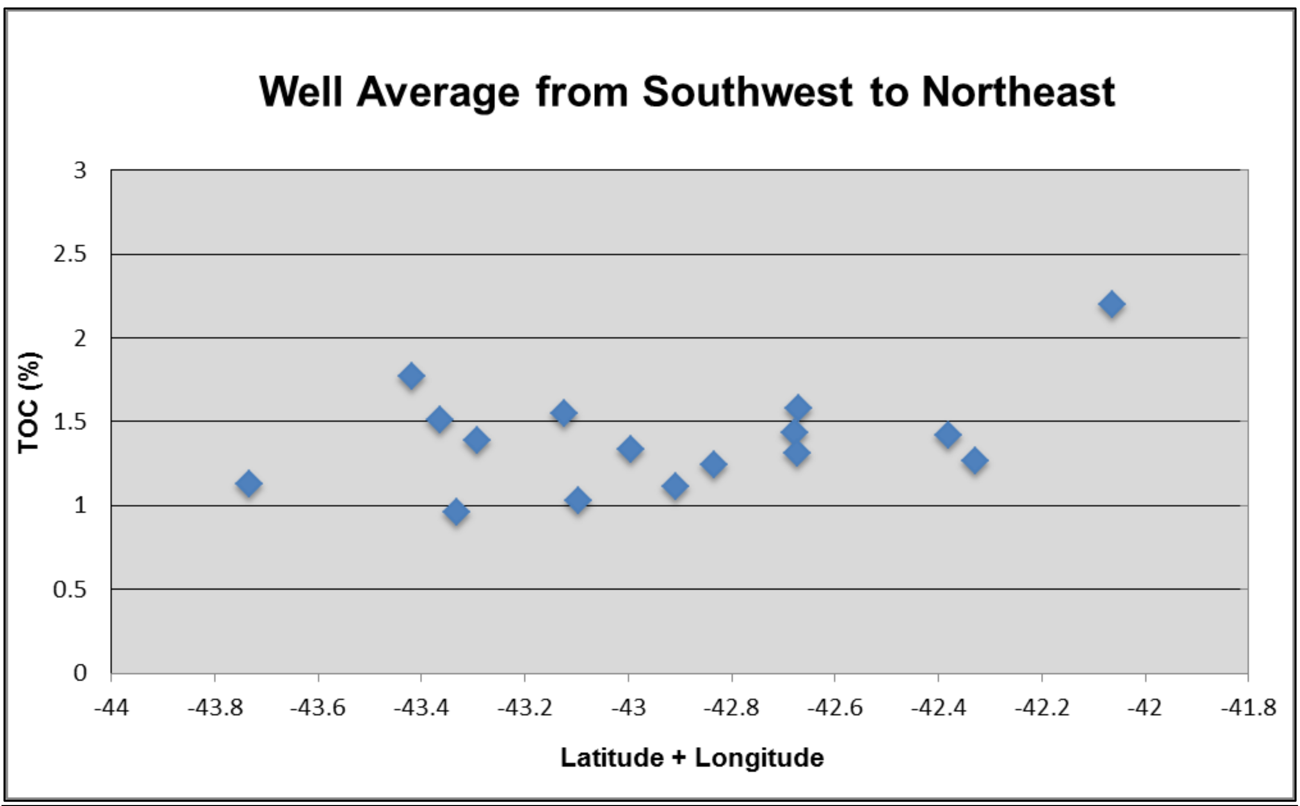


Chart 7

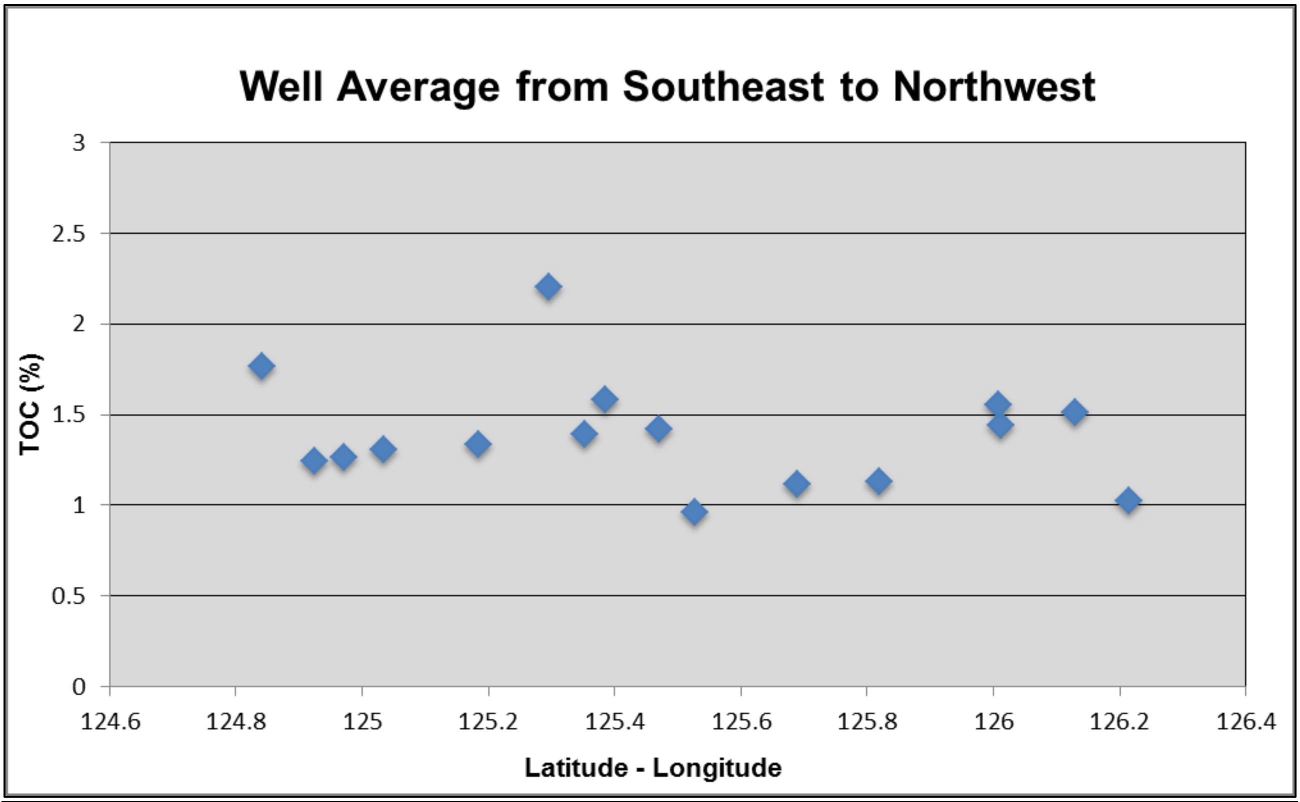


Chart 8

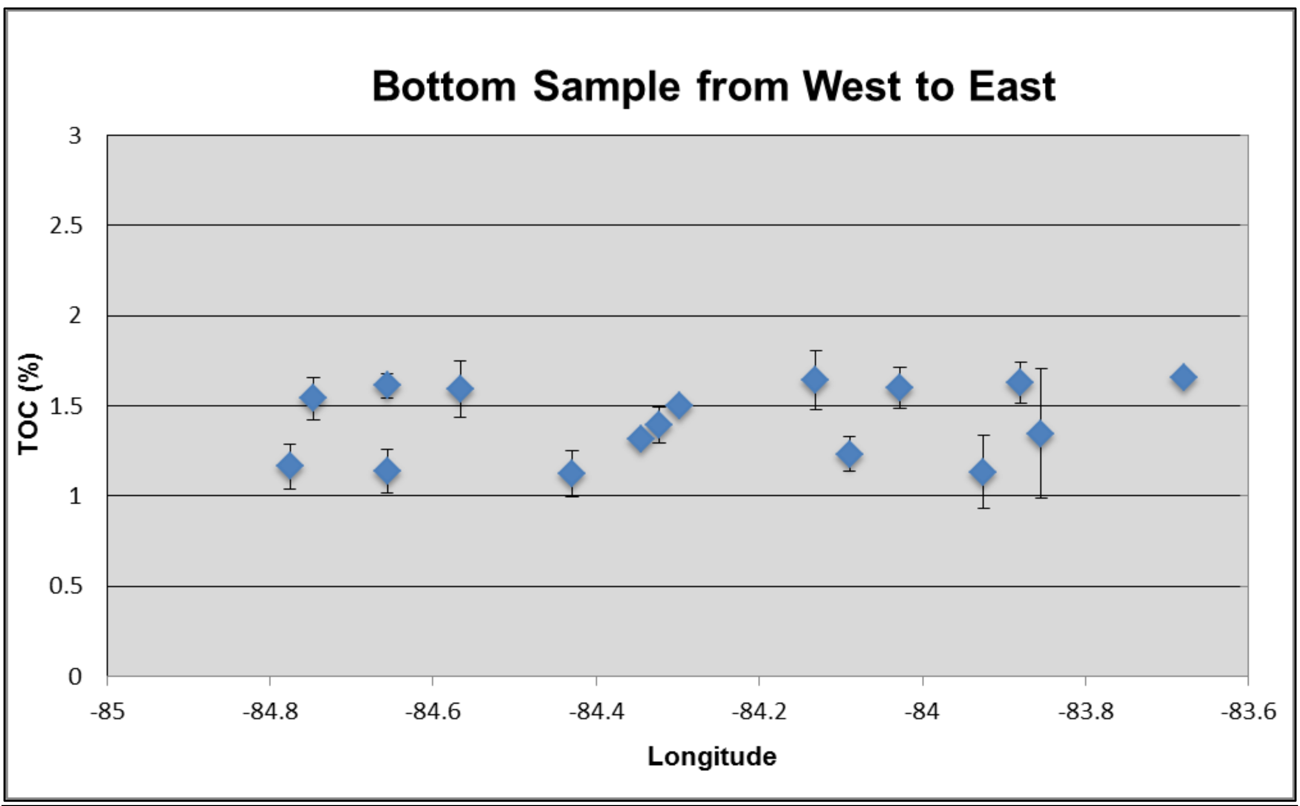


Chart 9

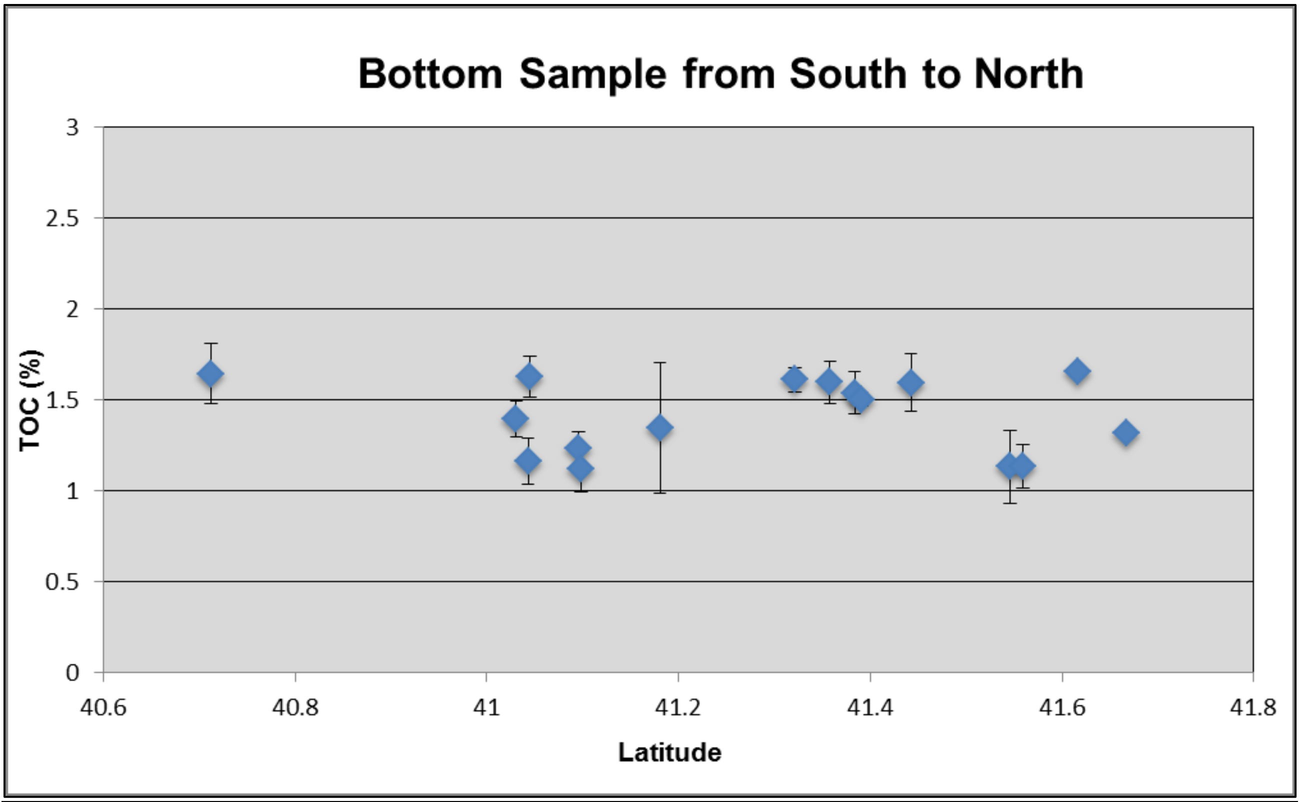


Chart 10

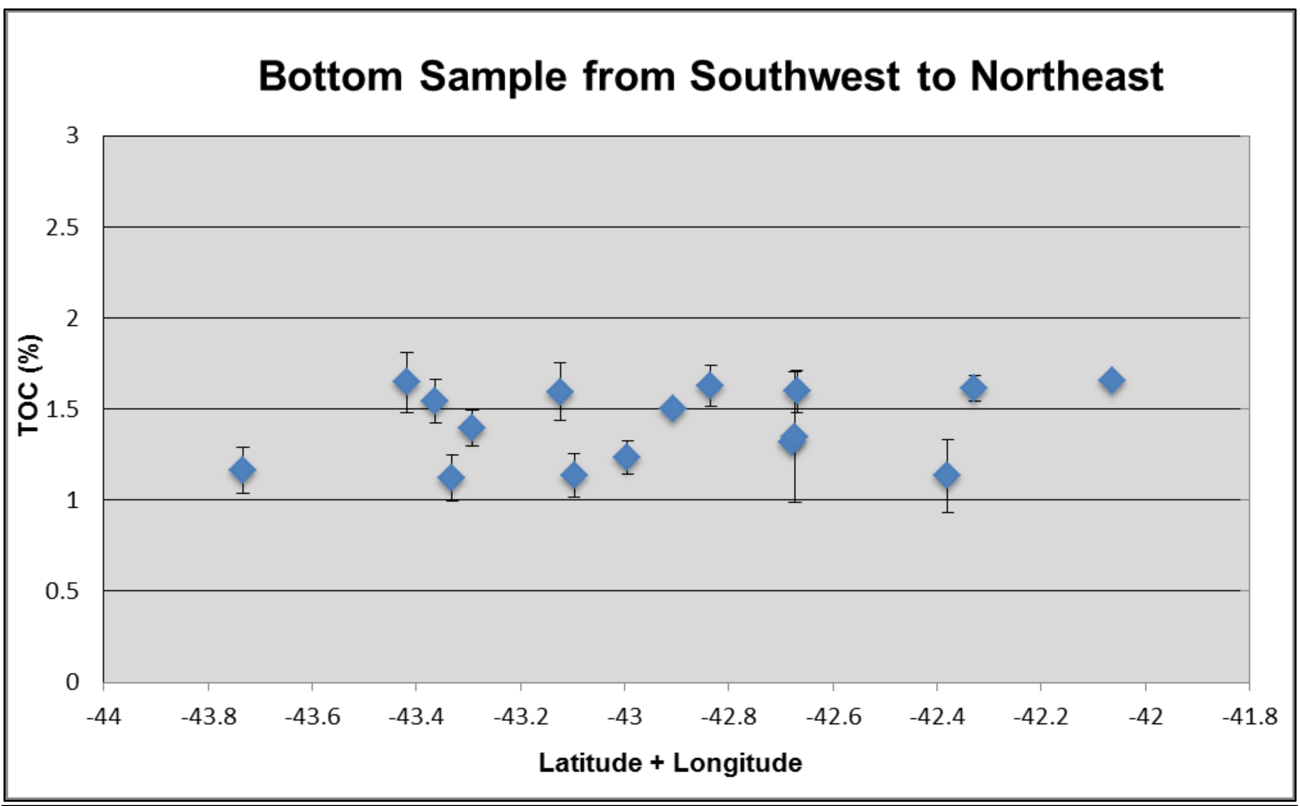


Chart 11

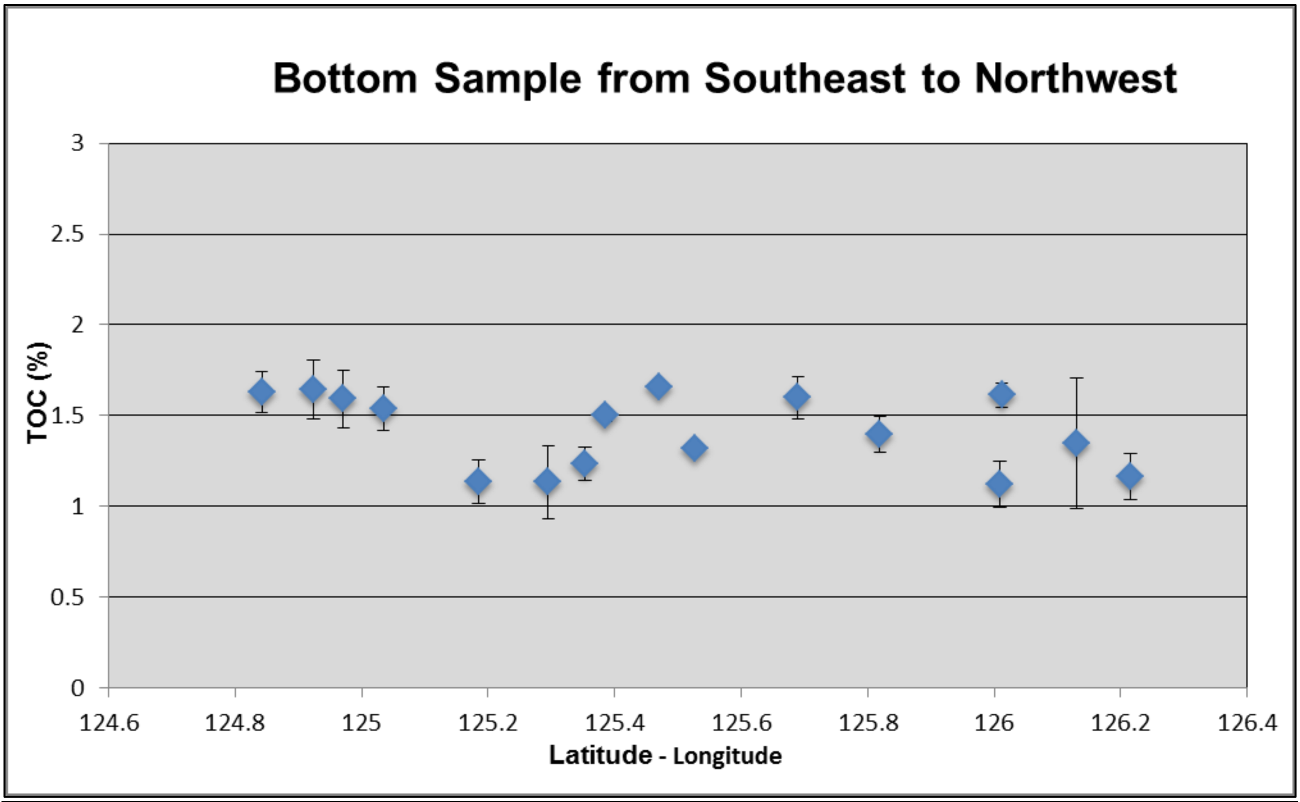


Chart 12

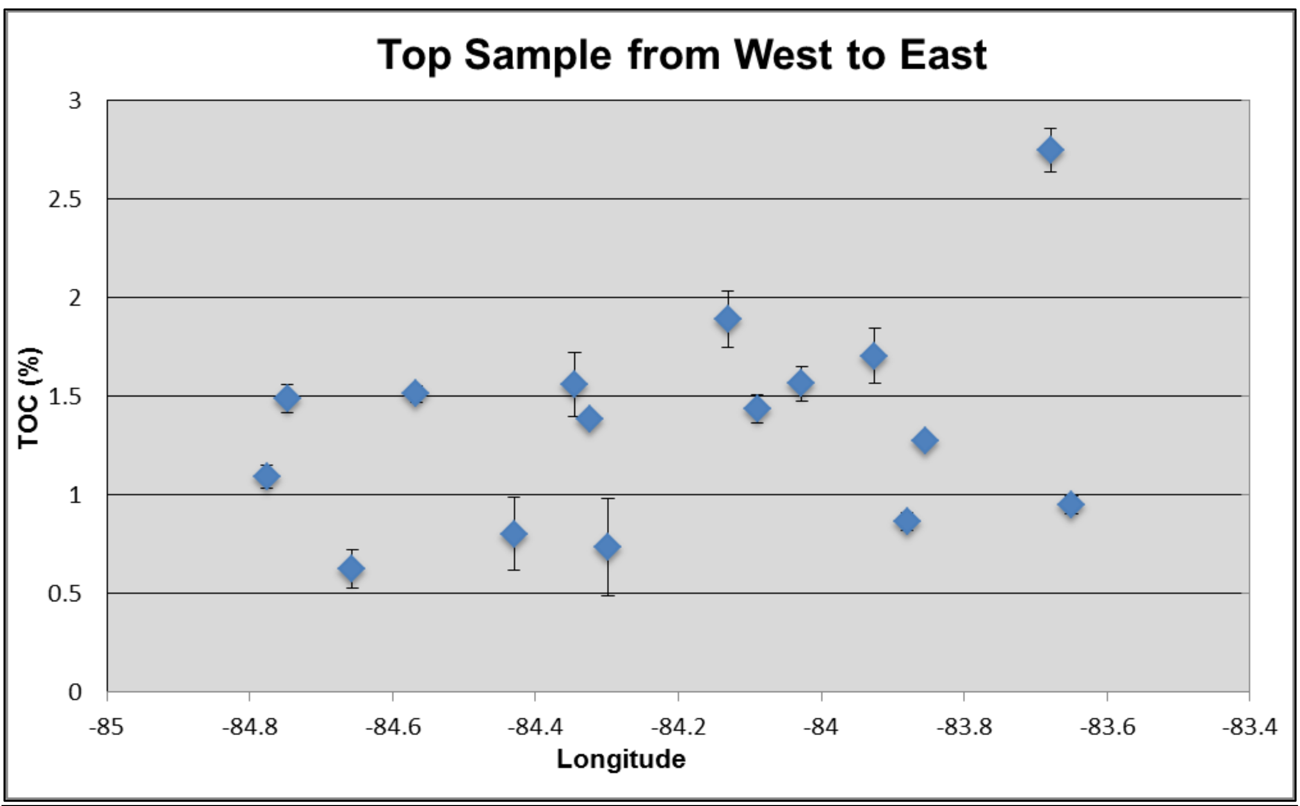


Chart 13

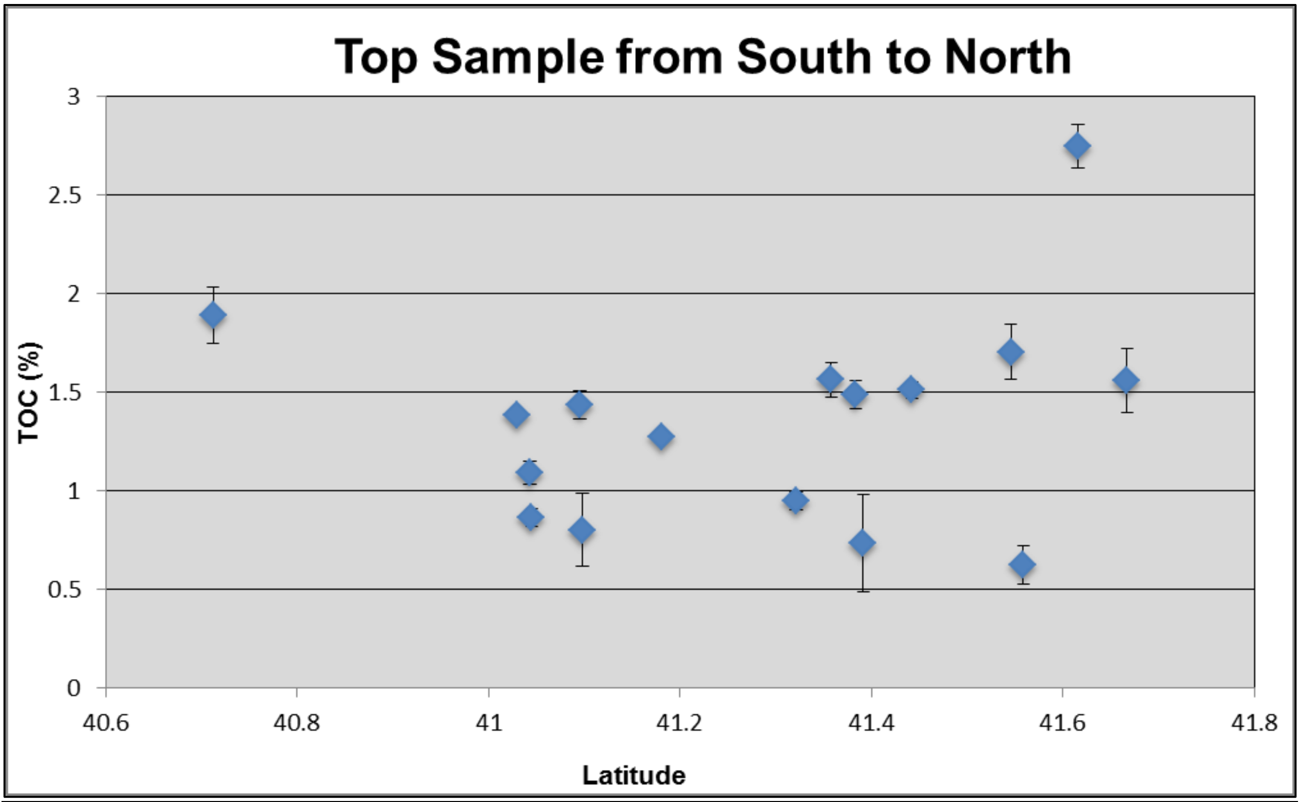


Chart 14

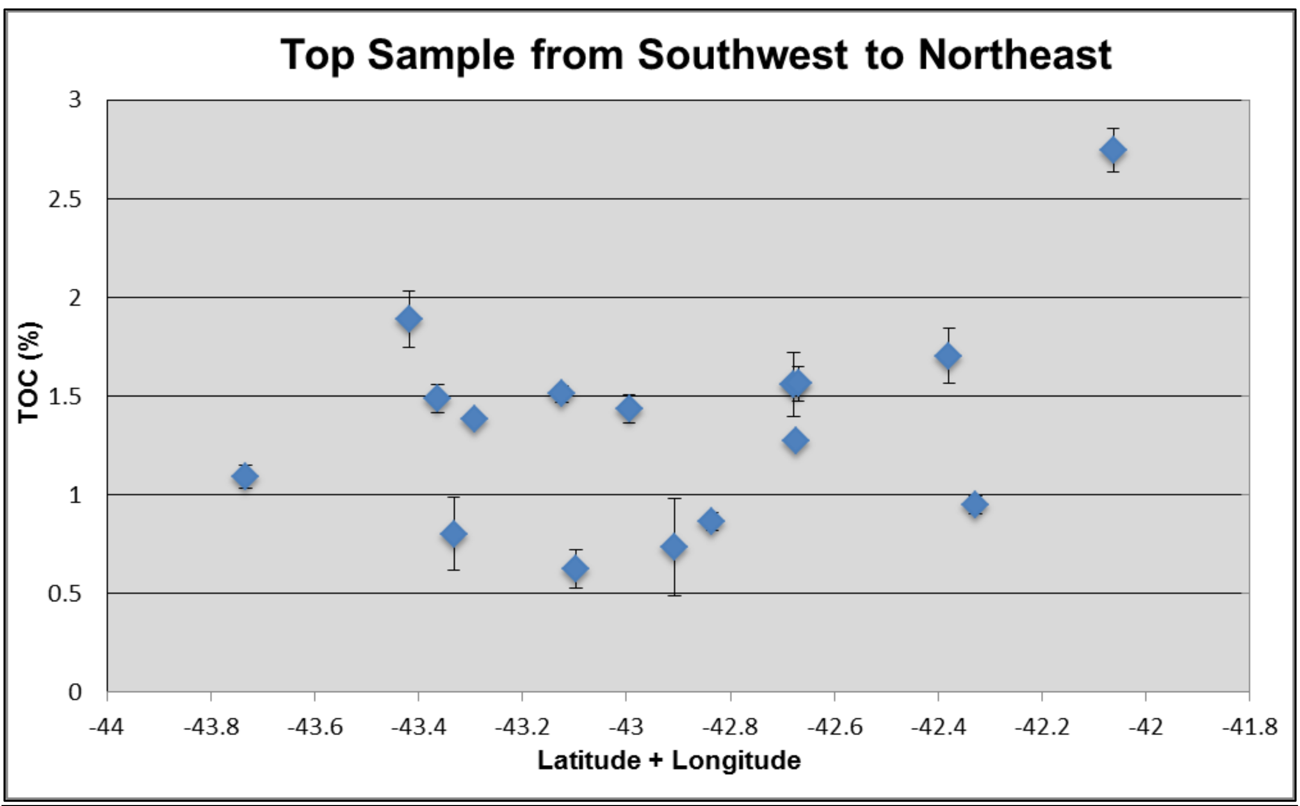


Chart 15

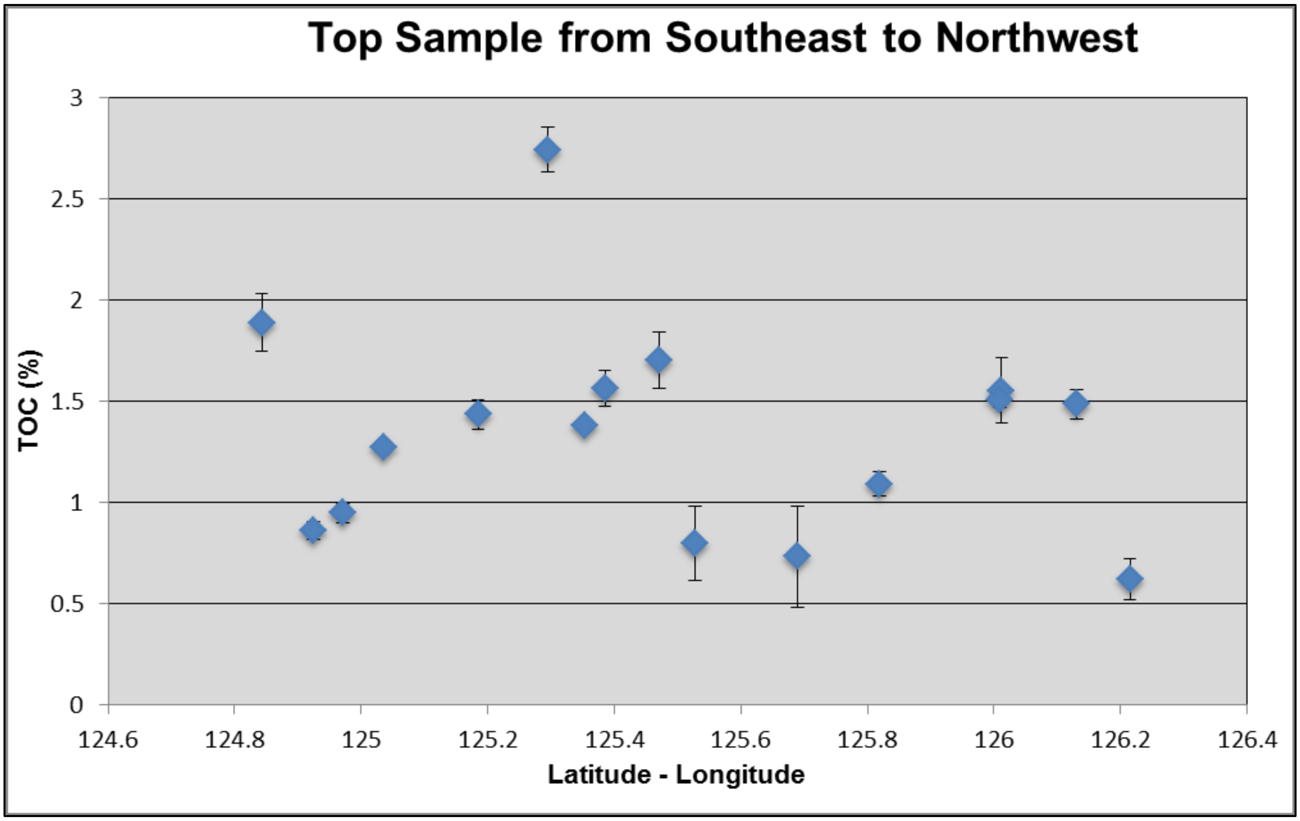


Chart 16

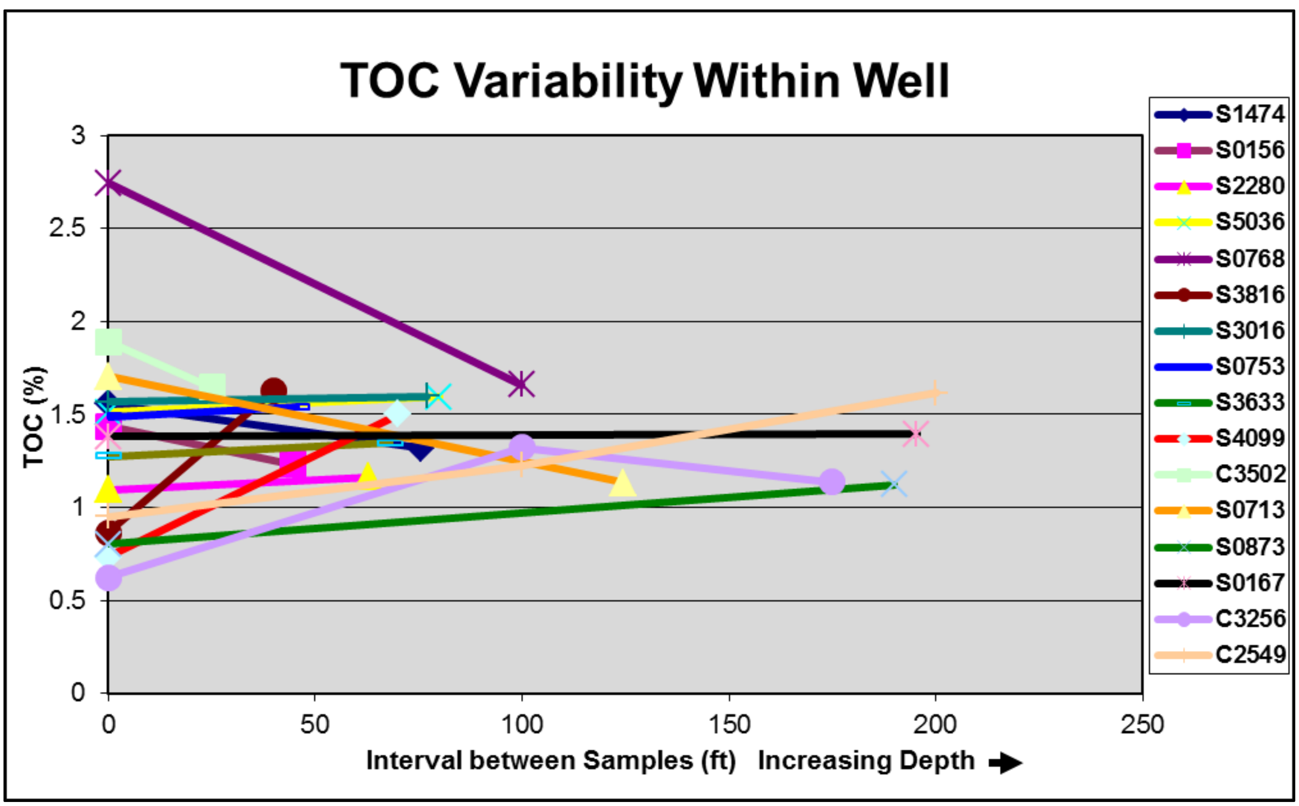
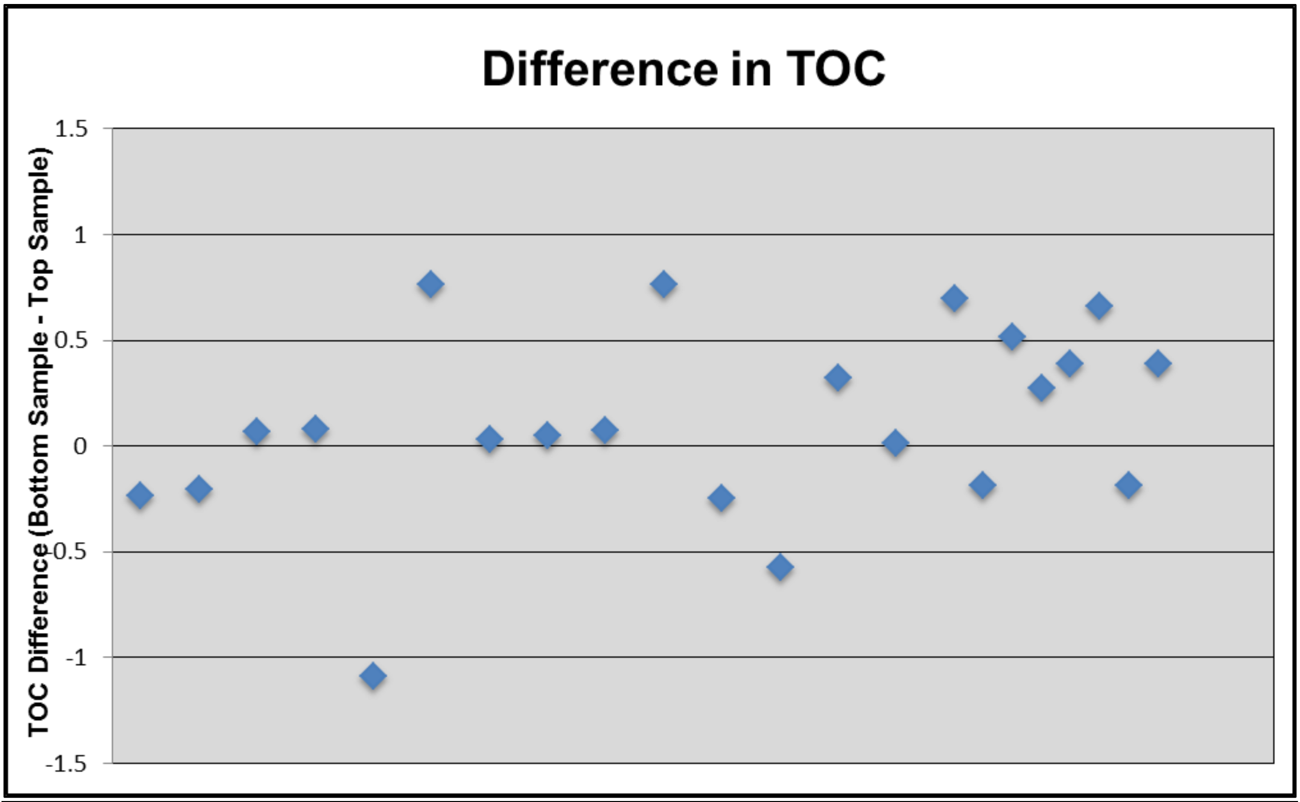


Chart 17



Discussion of Results

140 individual measurements were made on the 34 samples, the results of which are shown in Table 2. The average TOC for all of the samples was 1.38% with the average for each sample ranging from 0.62-2.75% (Chart 1). 27 of the 34 samples fell between 1-2% TOC. The range for the 140 individual measurements was 0.43-3.01%. The average TOC of the sixteen wells sampled was 1.39% with a range of 0.96-2.20%. 14 of the 16 well averages fell between 1-2% TOC. The average difference between the average TOC for the bottom and top samples for each well was 0.06% with a range of -1.09-0.77%. TOC in 11 of the 16 wells increased with depth (TOC of deeper sample higher than shallower sample from same well), but many of the increases were very slight (Chart 16).

The average interval between samples was 98.3 ft. with a range of 25-200 ft. Measurements made on the samples from near the Utica-Trenton contact do not indicate the presence of an organic rich basal layer. The TOC did vary by depth and location, but when plotted, the results show no strong trends in this variability. The range for the top samples (0.62-2.75%) was quite a bit larger than the bottom sample range (1.12-1.66%). This is likely due to the fact that the bottom samples were taken from a consistent depth within the Utica, while the top samples were taken from differing depths.

Oil and Gas Potential:

Most of TOC measurements for the Utica in the study area fall between 1-2% TOC, which is considered a fair level in the oil and gas industry. This level of TOC is capable of generating hydrocarbons, but not an amount that is especially conducive to shale gas production, especially if other formation characteristics such as thermal maturity, permeability and formation pressure are not ideal. According to thermal maturity maps of the Utica from Wickstrom et al (2012) wells C3502, S0156, S3816, S3633 and C2549 appear to be from an area of the Utica that is “thermally immature”; S0768, S3016, S0167, S0873, S2280 are in an area that could contain oil; S1474, S0713, S5036, S0753 and S4099 are in an area that could contain wet gas; and C3256 is in a dry gas window. The shallow depth of the Utica in the study area raises an environmental concern. Recent research by Davies et al (2012) has suggested a minimum of 600m (1968.5 ft.) between groundwater aquifers and hydraulic fracturing. The Utica was more than 1968.5ft below the surface in only two of the sampled wells (S1474 and C3256) much less that depth below groundwater aquifers. Overall, an average TOC of 1.38% for the study area suggests that this portion of Ohio does not appear to have great potential as a target for oil and gas exploration and exploitation, especially if other source rock characteristics are not ideal.

Reliability of Data:

To assess the accuracy of the measurements taken in this study, the data was compared to a study completed by Wickstrom et al (2012) that included TOC measurements of 14 wells within the study area. The data from Wickstrom et al is comparable to the findings of this study, which increases confidence in the data's accuracy. 12 of the 14 wells in their study had a TOC of 1-2%, whereas 14 of the 16 wells in this study fall within that range. The average for the 14 wells of the OGS study was 1.32%, only 0.07% less than the well average of 1.39% in this study.

The precision of the data was assessed by calculating the standard error for each sample. The standard error was calculated by dividing the standard deviation for a sample and then dividing it by the square root of the number of measurements taken on that sample (3-5). Standard deviation ranged from 0.035-0.719% with an average of 0.216%. Standard error averaged 0.107% over a range of 0.030-0.360%. There is the possibility that imprecise data are concealing key trends in the data. An attempt to eliminate seemingly suspicious measurements was made with the following outcome. Measurements more than 1 standard deviation from the mean of samples with a standard deviation of more than 0.3 were eliminated. 8 measurements from seven different samples from seven different wells were eliminated. These samples were S1474 2389-2390', S5036 1920-1930', S3633 1458' (2 measurements eliminated), S4099 1770-1800', C3502 1245', S0713 1911-1917', and S0873 1190-1195'. The new average standard deviation was 0.07% lower at 0.15% and the new average standard error was 0.03% lower at 0.075%. This more precise data set was mapped and graphed in the same manner as the initial data shown above, but this effort to "clean up" any potential errors in the data did not elucidate any trends in horizontal or vertical variability in total organic content. The changes to the data were not significant. Removing this data lowered the average for all samples and well average 0.01% to 1.37 and 1.38% respectively. 10 of the 16 wells now increased with depth (TOC of deeper sample higher than shallower sample from same well), and the average difference between top and bottom samples of the same well decreased from 0.06% to 0.04%. Tables with data for these statistical analyses follow.

Table 3: Standard Deviation and Standard Error for each sample.

Well	Depth (ft.)	Average	STD DEV	STD Error
S1474	2389-2398	1.56	0.324	0.162
	2467-2471	1.32	0.062	0.031
S0156	1359-1362	1.44	0.140	0.070
	1400-1410	1.23	0.186	0.093
S2280	1284-1292	1.09	0.116	0.058
	1347-1355	1.16	0.249	0.125
S5036	1840-1850	1.51	0.083	0.042
	1920-1930	1.59	0.317	0.159
S0768	1250-1260	2.75	0.220	0.110
	1340-1350	1.66	0.058	0.029
S3816	1290-1300	0.86	0.088	0.044
	1330-1340	1.63	0.227	0.114
S3016	1583-1653	1.56	0.176	0.088
	1677-1713	1.60	0.230	0.115
S0753	1794-1821	1.49	0.146	0.073
	1849-1857	1.54	0.239	0.119
S3633	1390	1.27	0.035	0.020
	1458	1.35	0.719	0.360
S4099	1770-1800	0.73	0.495	0.247
	1850-1860	1.50	0.060	0.030
C3502	1220	1.89	0.284	0.142
	1245	1.65	0.366	0.164
S0713	1785-1794	1.70	0.240	0.139
	1911-1917	1.13	0.351	0.203
S0873	1190-1195	0.80	0.320	0.185
	1380-1385	1.12	0.283	0.127
S0167	1174-1180	1.38	0.051	0.023
	1394-1351	1.39	0.220	0.098
C3256	2090	0.62	0.220	0.098
	2190	1.32	0.175	0.078
	2265	1.14	0.267	0.120
C2549	880	0.95	0.092	0.046
	980	1.23	0.167	0.075
	1080	1.61	0.150	0.067
Average	1479.8	1.38	0.216	0.107

Table 4: Change in individual sample and well averages after elimination of suspect data. Columns labeled "New" represent average TOC for individual samples and wells after suspect data was eliminated. Columns labeled "Change" represent the difference between the original and "New" averages.

Well	Depth (ft.)	TOC	New TOC	Change TOC	Well Ave. TOC	New Well Ave. TOC	Change Well Ave.
S1474	2389-2398	1.56	1.70	0.140	1.44	1.51	0.070
	2467-2471	1.32	1.32				
S0156	1359-1362	1.44	1.44		1.34	1.34	
	1400-1410	1.23	1.23				
S2280	1284-1292	1.09	1.09		1.13	1.13	
	1347-1355	1.16	1.16				
S5036	1840-1850	1.51	1.51		1.55	1.47	-0.078
	1920-1930	1.59	1.44	-0.156			
S0768	1250-1260	2.75	2.75		2.20	2.20	
	1340-1350	1.66	1.66				
S3816	1290-1300	0.86	0.86		1.25	1.25	
	1330-1340	1.63	1.63				
S3016	1583-1653	1.56	1.56		1.58	1.58	
	1677-1713	1.60	1.60				
S0753	1794-1821	1.49	1.49		1.51	1.51	
	1849-1857	1.54	1.54				
S3633	1390	1.27	1.27		1.31	1.27	-0.035
	1458	1.35	1.28	-0.071			
S4099	1770-1800	0.73	0.49	-0.246	1.12	0.99	-0.123
	1850-1860	1.50	1.50				
C3502	1220	1.89	1.89		1.77	1.84	0.072
	1245	1.65	1.79	0.145			
S0713	1785-1794	1.70	1.70		1.42	1.32	-0.101
	1911-1917	1.13	0.93	-0.203			
S0873	1190-1195	0.80	0.99	0.184	0.96	1.05	0.092
	1380-1385	1.12	1.12				
S0167	1174-1180	1.38	1.38		1.39	1.39	
	1394-1351	1.39	1.39				
C3256	2090	0.62	0.62		1.03	1.03	
	2190	1.32	1.32				
	2265	1.14	1.14				
C2549	880	0.95	0.95		1.26	1.26	
	980	1.23	1.23				
	1080	1.61	1.61				
Average		1.38	1.37	-0.006	1.39	1.38	-0.006

Table 5: Change in the difference between bottom and top samples after the elimination of suspect data

Well	Depth (ft.)	Difference	New Difference	Change
S1474	2389-2398	-0.24	-0.38	-0.140
	2467-2471			
S0156	1359-1362	-0.20	-0.20	
	1400-1410			
S2280	1284-1292	0.07	0.07	
	1347-1355			
S5036	1840-1850	0.08	-0.07	-0.156
	1920-1930			
S0768	1250-1260	-1.09	-1.09	
	1340-1350			
S3816	1290-1300	0.77	0.77	
	1330-1340			
S3016	1583-1653	0.03	0.03	
	1677-1713			
S0753	1794-1821	0.05	0.05	
	1849-1857			
S3633	1390	0.07	0.00	-0.071
	1458			
S4099	1770-1800	0.77	1.01	0.246
	1850-1860			
C3502	1220	-0.25	-0.10	0.145
	1245			
S0713	1785-1794	-0.57	-0.77	-0.202
	1911-1917			
S0873	1190-1195	0.32	0.14	-0.184
	1380-1385			
S0167	1174-1180	0.01	0.01	
	1394-1351			
C3256	2090	0.51	0.51	
	2190			
	2265			
C2549	880	0.66	0.66	
	980			
	1080			
Average		0.06	0.04	-0.023

Conclusions

Based on the low to moderate TOC levels discovered in this research and information from a third party study, oil and gas are likely present in much of the study area, but probably not in large enough amounts for economic production. TOC levels for the area averaged a significant but not abundant 1.38%. Averages for each individual sample were within a relatively small range of 0.62-2.75%. The TOC in the area did vary with depth within the formation, depth below the surface, and location; but no significant trends were discovered in this variability. It is possible that TOC contents are heterogeneous within the formation and no broad trends exist in the study area. There was no evidence for an organic-rich layer at the base of the Utica.

Future Work

Multiple avenues of further research in the Total Organic Carbon of the Utica Shale of Northwest Ohio could be taken to build upon this study. The first and simplest path would be to take more TOC measurements on the samples already collected. An increase in measurement frequency would mitigate errors from inaccurate data that could be obfuscating real trends in the data. Other routes exist involving an increase in the amount of samples tested. To identify trends too narrow in scope for the original sampling plan, additional samples within the study area would be acquired. For trends too broad, samples from outside the study area should be targeted. To search for a trend in horizontal variability samples would be acquired from additional wells within or without the original study area. Vertical variability trends could be revealed by sampling from multiple depths in new wells or sampling from more depths in some or all of the original 16 wells. Research into other properties of the Utica samples could also be pursued. X-Ray Diffraction could be used to complete a mineralogical analysis of the samples, which could then be compared to the previously measured TOC values to check for a correlation between mineralogy and TOC. Additionally, analyses of other factors controlling hydrocarbon potential such as thermal maturity, porosity, permeability, and formation pressure could be made.

Acknowledgments

I would now like to acknowledge the people that gave me guidance and support while completing this thesis and the organizations that provided me with the opportunity to do so. First and foremost I would like to thank Dr. David Cole for playing his role as my research advisor so well. His guidance led me to this project, he provided or helped me obtain the resources necessary for its completion, his questions helped me gain a much needed (increased) understanding of the research process, and feel that I am a better Earth Scientist (in training) thanks to him. I would like to thank the people of the Subsurface Energy Materials Characterization & Analysis Lab (SEMCAL) at the Ohio State University School of Earth Sciences for providing me with the ability to make the measurements necessary for my research. Specifically I would like to thank Dr. Sue Welch, Dr. Julie Sheets, and Brandon McAdams for developing and then teaching me the methodology for the lab work. I am grateful to the Ohio Geological Survey for providing me with an internship, my samples for this research, and advice throughout the project. I would like to thank Greg Schumacher of the Survey for his work in providing me the samples for my research; and Chris Perry, Ron Riley, and Matt Erenpreiss for providing me with advice and education on my research subject.

References Cited

Gutierrez, T., Osori, N., and Restrepo, D., 2009, Unconventional Natural Gas Reserviors: Energética, No. 41, December-July, 2009, pp. 61-72 Universidad Nacional de Colombia.

Schumacher, B.A. Methods for the Determination of Total Organic Carbon (TOC) in Soils and Sediments, EPA/600/R-02/069 (NTIS PB2003-100822), U.S. Environmental Protection Agency, Washington, DC, 2002.

Ryder, R.T., 2008, Assessment of Appalachian basin oil and gas resources: Utica-Lower Paleozoic Total Petroleum System: U.S. Geological Survey Open-File Report 2008–1287, 29 p.

Davies, R., Mathias S., Moss, J., Hustoft, S., and Newport, L., Hydraulic fractures: How far can they Go?, Marine and Petroleum Geology, Available online 24 April 2012, ISSN 0264-8172, 10.1016/j.marpetgeo.2012.04.001. (http://www.sciencedirect.com/science/article/pii/S0264817212000852?v=s5)(April 2012).

Hansen, M., 1997, The Geology of Ohio-The Ordovician: Ohio Geological Survey Quarterly Newsletter, Fall 1997, p. 1-6.

Yost, A., 2011, Research Plan Utica Shale Characterization and Development: http://www.pttc.org/workshops/eastern_062111/eastern_062111_Yost.pdf (March 2012).

Wickstrom, L., Perry, C., Riley, R., and Erenpreiss, M., The Utica-Point Pleasant Shale Play of Ohio: http://www.dnr.state.oh.us/geosurvey/tabid/23014/Default.aspx (October 2011).